Raspberry Pi in the Sky

Restrictions in the United Kingdom against airborne amateur transmissions, including prohibiting the use of APRS, make for unique workarounds. This article describes how the open-source hardware Raspberry Pi has been used for transmitting slow-scan digital photos from a high-altitude balloon payload using a low-power transmitter.

By Dave Akerman*

Since the United Kingdom has restrictions against airborne amateur transmissions, including prohibiting the use of APRS, in this article Dave Akerman describes how he uses the very popular open-source hardware Raspberry Pi for transmitting slow-scan digital photos from a high-altitude balloon (HAB) payload using the permitted non-licensed low-power transmitter. The following story is about flying a Raspberry Pi as part of a payload on a high-altitude balloon.

PIE1: Raspberry Pi Sends Live Images from Near Space

High-altitude ballooning (HAB) is a growing hobby in which enthusiasts use standard weather balloons to put small payloads (typically 100 gm to 1 kg) into "near space" at altitudes of around 30 km or so, carrying a tracking device (so the balloon position is known throughout the flight), usually some sensors (temperature, pressure, etc.), and often a video or a still camera storing to an SD card for later retrieval.

The job of the tracker is to read the location from the GPS receiver, possibly also read some sensors, and then format and send a telemetry sentence to the ground over a low-power radio link. In the UK, flights happen after the predicted path is known to be safe (avoiding airports and densely populated areas ,for example) and permission has been gained from the Civil Aviation Authority (CAA).

Here in the UK the tracking system uses the 70-cm radio band (around 434 MHz) using RTTY to send the telemetry down to a number of ground stations run by other enthusiasts. Telemetry from all receivers is sent to a central server that then drives a live map which can be viewed by anyone with an internet connection. The system works extremely well and has been used

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This material appears here courtesy the author and is also available on his blog: <http://www.daveakerman.com/?p=592>.

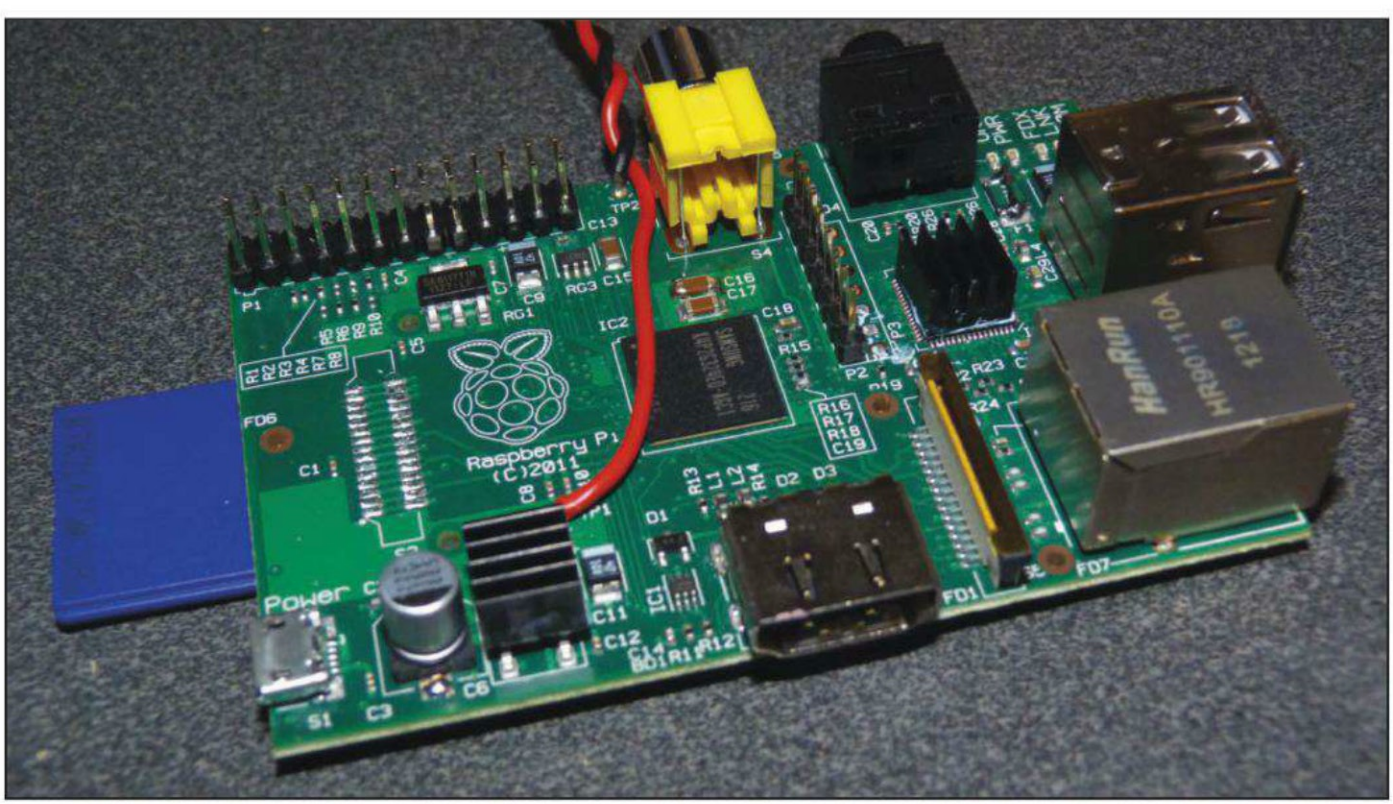

Photo 1. Additional heat sinks attached to the USB/ETH chip and the 3.3-volt regulator on the Raspberry Pi board.

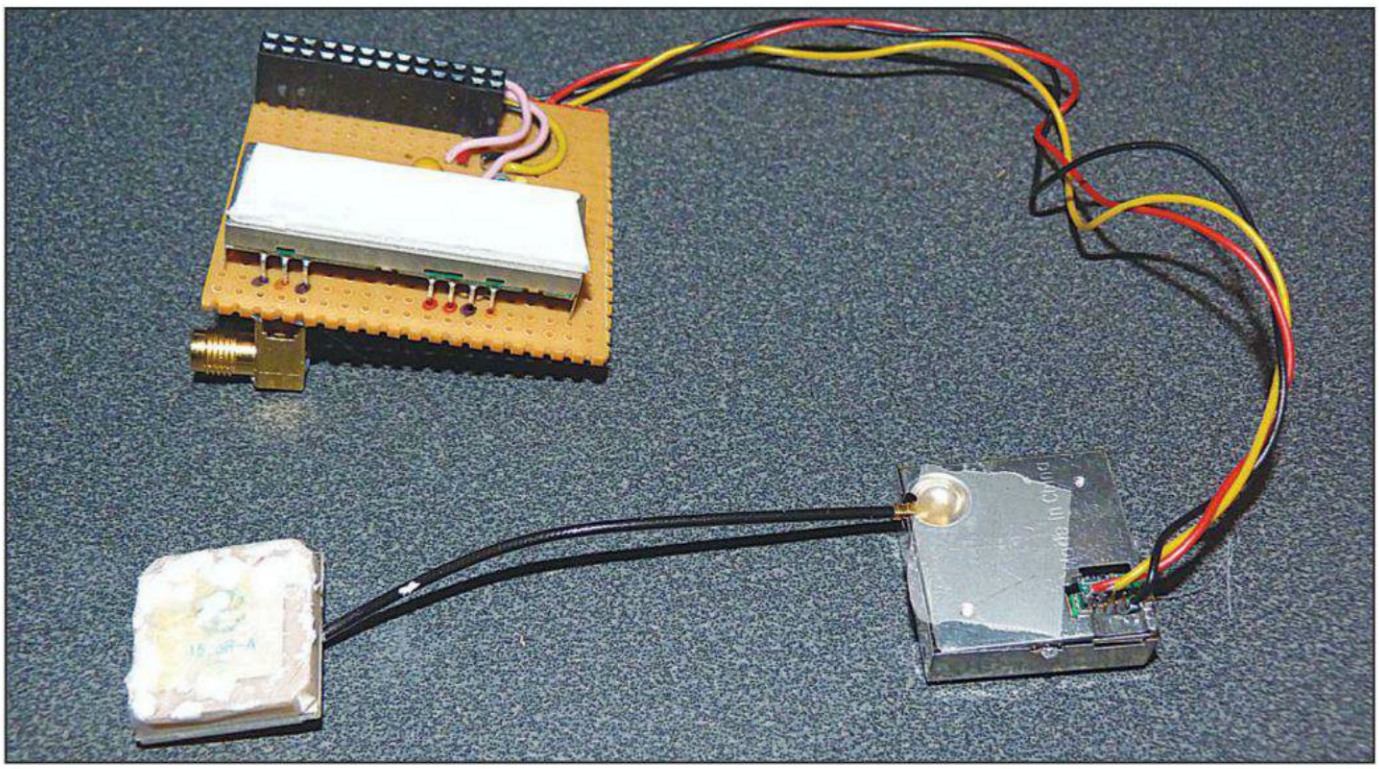

Photo 2. Experimental printed circuit board with the Radiometrix NTX2.

to track payloads at distances of 800 km and more even though the transmitter is limited by UK law to 10 mW ERP.

In early May I received my first Raspberry Pi computer (http://http://www.raspberrypi.org/), and having flown several high-altitude balloons before I thought about using one as a flight computer. In almost all of my previous flights I used Arduino Mini Pro boards (http://http://www.arduino.cc/), and these are ideal—tiny, weigh almost nothing, simple. and need very little power. I looked at the Pi and saw none of these desirable features! What I did see, though, was a USB port offering quick, easy, and inexpensive access to a webcam, meaning that for the first time I could have live images (SSDV) sent down by my payload—something that hasn't been done very often.

"Near Space" is a fairly hostile environment – less than 1% atmosphere, temperatures down to –50 degrees C or so—and if anything goes wrong it's likely to stay wrong. The radio link is one-way, so there's no chance of remotely doing a "pseudo reboot" let alone powering off then on again! Descent can be violent, as can the landing, so even things such as SD card sockets can represent a potential failure mode.

The Pi is a step up in complexity from the usual boards we use, which have no SD cards, or USB, or even an operating system, so the extra power and capability does come at a price, and the first one is an increase in the power requirement from around 60 mA to over 500 mA, and that of course means much higher power dissipation.

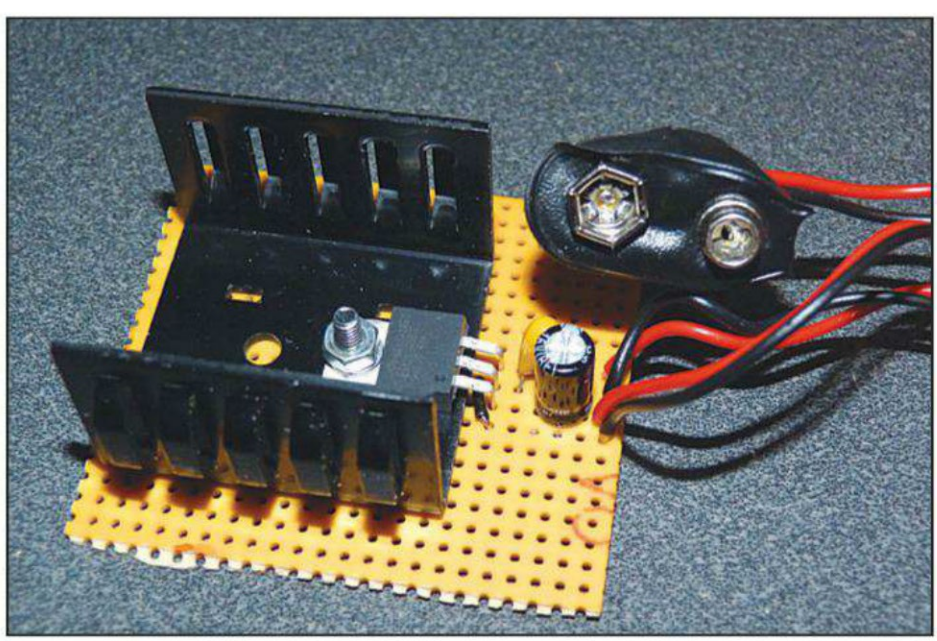

Photo 3. Linear regulator.

People often worry about the low temperatures in near space, but when your payload is generating a few watts of power that is not likely to be a problem! I was much more concerned with how hot it was going to get inside the payload, so I added some heat sinks to the Pi. Photo 1 shows the Raspberry Pi with the additional heat sinks.

I used special thermal adhesive to glue heat sinks to the USB/ETH chip and to the 3.3V regulator. Both get warm but normally not hot, and I feared that at 1%

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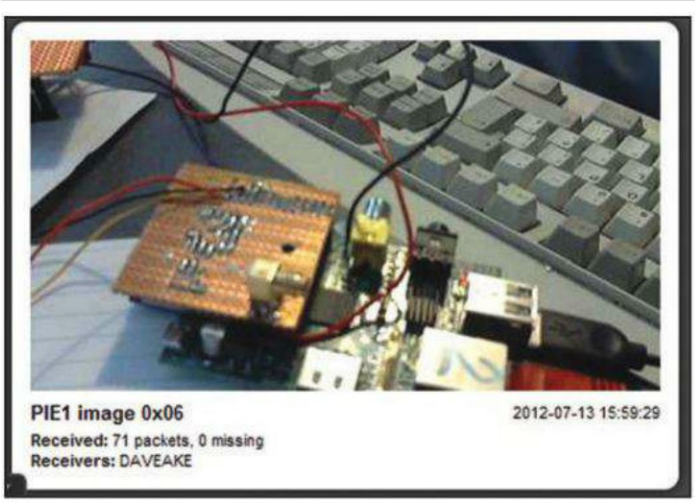

Photo 4. The Pi makes a self-portrait.

atmosphere (so less convection) they'd possibly get too hot. You can also see two wires carrying 5V directly to the Pi; soldered joints are more reliable than using a connector. Another modification was to remove the S2 video connector to make space for components on my expansion board. The final modification was to short out the USB fuses since my webcam's current requirement exceeds their rating. I then added a small piece of strip board carrying a Radiometrix® NTX2 radio transmitter (http://www. radiometrix.com/content/ntx2; see photo 2) to send the telemetry and images down to the ground, and connected that to a simple GPS receiver on a wire tail so it could be kept away from the transmitting devices.

The final item for a basic tracker is a suitable power supply. Energizer® lithium AA cells are the obvious choice, since they are specified to work down to –40 degrees C and are very good at high currents (we need over 500 mA for the Pi plus webcam). On the way to 30 km the outside will get down to –50 degrees C, and even with minimal insulation the batteries will self-heat to stay within their operating range.

The Pi needs 5V supplied to it, so I used an external LDO (Low DropOut) linear regulator (photo 3) fed from 6 AAs which would supply enough voltage to the regulator until they were pretty much flat. With the regulator dissipating up to 3 watts it needed and got a heatsink. This is a lot of heat to get rid of in a payload (which is insulated, because you don't want it to get too cold either, because that can affect other parts). I had some switched mode regulators ordered, but they didn't arrive in time for my flight, so it went up with the linear regulator.

The usual technique with the NTX2 is to send the "1" and "0" values in RTTY by waggling a general-purpose I/O pin up and down at the correct rate—e.g., every 20 ms for the common 50-baud data rate. This is easy when you're programming a bare-metal AVR or PIC; just use a delay routine or, as in my trackers, a timer interrupt. However, the Pi runs a non-real-time operating system, so I could not rely on accurate timing especially if the operating system was busy taking a photo from the webcam. There are other options, but I opted for the simplest one—connect the NTX2 to the serial port. RTTY is just normal RS232-style serial marks and spaces and stop bits, etc., so why not let the hardware UART do the timing for me?

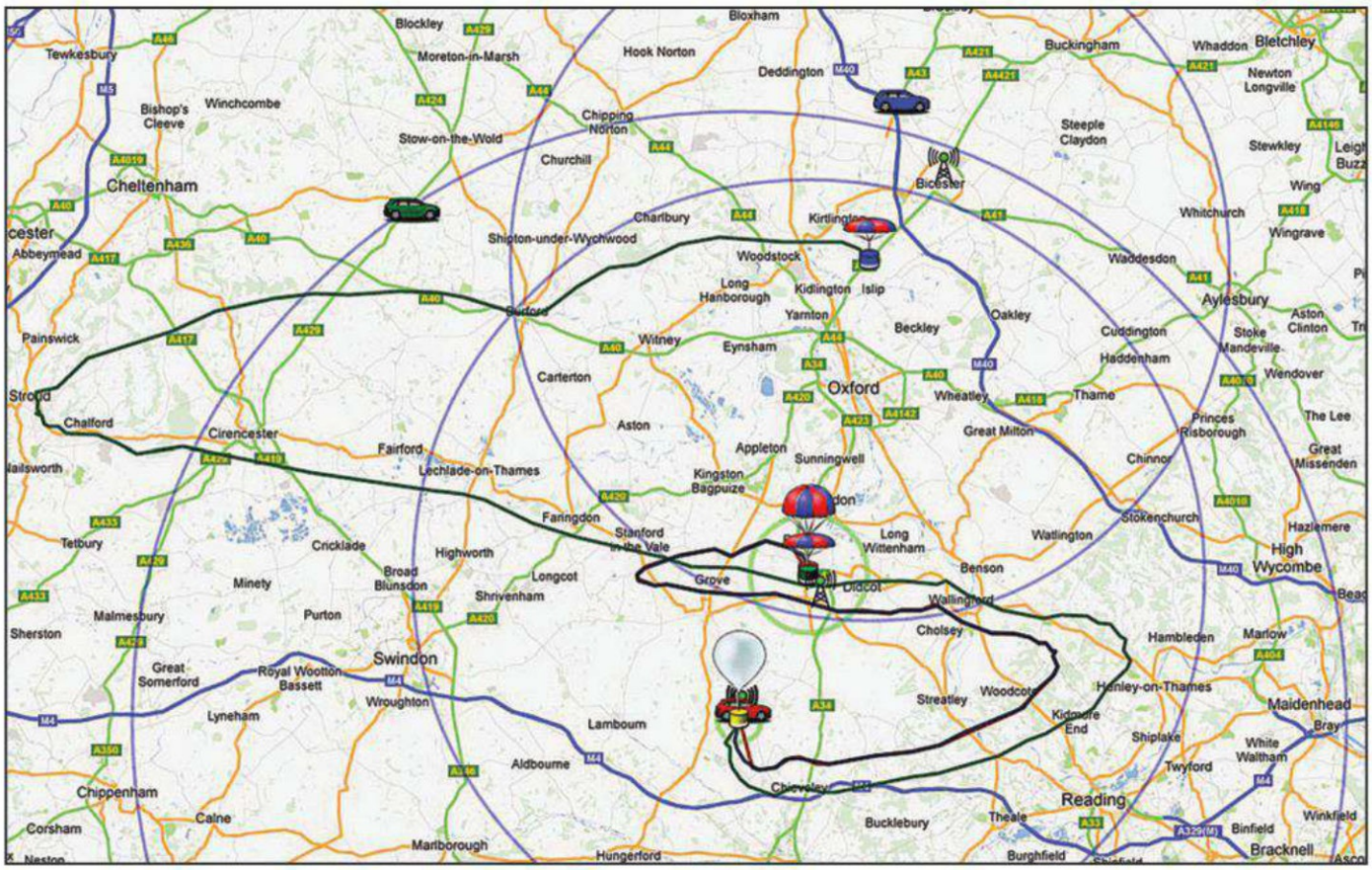

Figure 1. Map of tracking the two launches. The location of the UAVA landing is nearest the launch point.

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It didn't take long to write a small "C" program that opened the serial port at 4800 baud, read enough GPS strings to find the longitude, latitude, and altitude, and then close the port and re-open at 300 baud (I found that switching baud rates without closing and opening wasn't always reliable.) to send out a formatted telemetry string.

Of course, to do this I had to disable the login prompt on the serial port, and stop the kernel debug messages being sent to it, but all in all it was simple. All of this was done using the standard Debian image on a 4GB SD card.

Now for the live images. I had to apply a patch to Debian after which it happily recognized the webcam as /dev/video0. I tried a few webcams and settled on the Logitech C270, which is reasonable quality, light, and cheap (in case the payload goes missing!). I tried several webcam imaging programs and found fswebcam (http://www.firestorm.cx/fswebcam/) to be the best (worked without fiddling, yet with enough options to tailor the picture-taking).

Photo 5. The payload package with the various components installed.

Photo 6. The Raspberry Pi payload package.

Remember that the radio system has low bandwidth and with a typical flight lasting two hours or so we don't have time to send large images, so there's no point using the very best webcam and the highest resolution. I settled on 432 × 240 pixels with 50% compression as a good compromise between quality and download speed. I measured the webcam current and it went from 50 mA at idle to 250 mA peak when taking a picture, hence the need to short out the USB fuse (140 mA maximum).

A simple shell script took a photo every 30 seconds, saving them on the SD card so that the tracker program could choose the "best" image (largest jpeg!) for transmission. Each chosen image was then converted to the form for download (split into blocks each with FEC) before being sent one block at a time. I interspersed the image data with telemetry—four image packets for each telemetry packet. Photo 4 shows the Pi making a self-portrait.

With the completed tracker tried and tested, and permission for the flight gained from the CAA, I built a container for the Pi, webcam, GPS, aerials, batteries, and regulator. I didn't want to use too much insulation, as the payload package needed to not get too hot with 3–5 watts being generated inside, so I used 10-mm thick EPX material (see photo 5). Any thinner would have been too fragile.

As the launch day approached the wind predictions consistently showed an S-shaped flight path from the launch site near my home in West Berkshire, initially flying south, then east, then briefly north before turning west at higher altitudes. Then during descent it would go through those directions in the opposite sequence, finally landing somewhere in the Chilterns. With the weather (rain, as it was summer) looking okay, if not ideal, I ordered and collected the gas for the balloon. I obtained permission for two flights (figure 1) so a friend and fellow enthusiast Anthony Stirk, 2EØUPU, could come down and fly two new trackers that he'd built. With three trackers and two flights we opted to fly a large balloon with a small light tracker, then fly a sec-

ond balloon with Anthony's larger tracker and a GoPro® HD video camera, and then attach the Pi to that. After a bit more thought we decided to add a third tracker as a backup to make sure we got that GoPro back!

The flight day came, and so did the rain, but that was predicted to pass so we waited and then went to the launch site as it eased to a light drizzle. First was the larger balloon with the small payload, so Anthony could make an attempt at the altitude world record. Then came the rather more complicated flight with my Pi payload at the top, then the GoPro payload, and finally my backup "Buzz" tracker which I'd flown before. Photo 6 shows the PIE1 payload package waiting to go. Photo 7 shows the balloon to which it is being attached.

Photo 7: The payload string being attached to the balloon.

The entire train of parachute and three payloads weighed 1 kg (same as my very first payload), and from the balloon to the lowest payload it was around 60 meters in length! The launch was interesting, as initially the wind kept the balloon low and the line was nearly horizontal! After a short wait the wind eased and the balloon lifted and got to an angle where it was safe to launch after running toward the balloon as fast as I could! I was relieved to see it all lift nicely, and that huge train made an impressive sight as it went up toward the clouds.

The launch site is in the village where I live, so afterwards we drove the chase cars back to my house to our "mission control" (see photo 8) to watch the tracking and images from there. The predicted landing spots meant there was no hurry to get back into the cars to chase the payloads, so we had plenty of time to watch the images come in (photos 9 and 10) and grab some food.

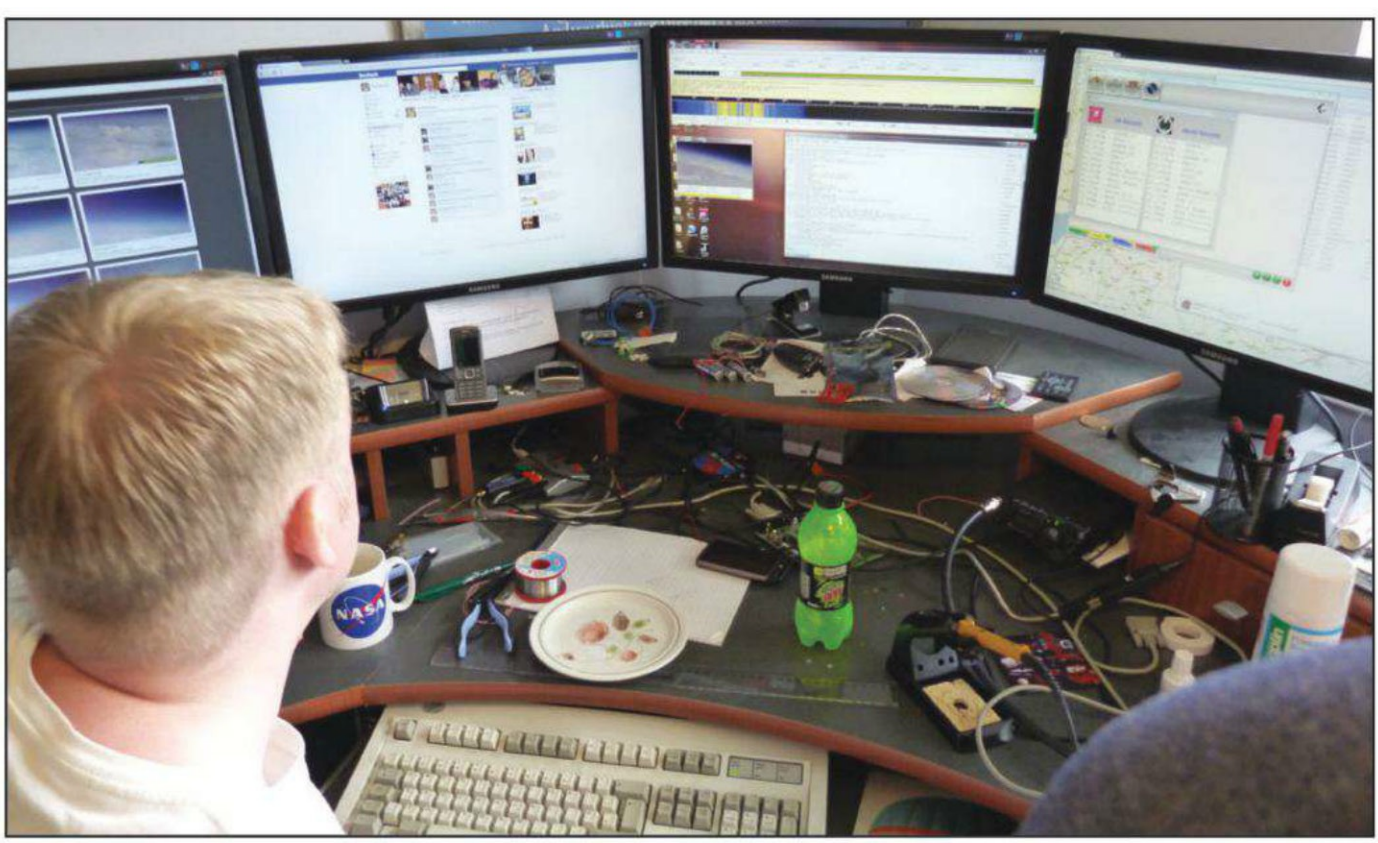

Photo 8: Mission control for the balloon launches.

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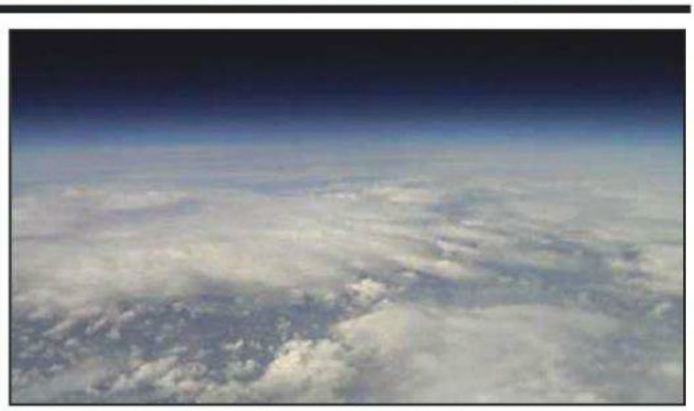

Photos 9 & 10: Two images sent from the Raspberry Pi in the Sky payload package.

The first flight was the altitude attempt, using a make and size of balloon that from experience either bursts early at around 27 km or exceeds specification to reach 40 km or so. In fact, the top few places in the altitude record table are all held by that make/size. Anthony was, of course, watching the altitude reading in the telemetry quite closely!

Meanwhile, I was much more interested in how well the Raspberry Pi was doing. The GPS position was still showing the position at the launch site, which is a sure sign of interference to the GPS signal. I've not determined yet which it is, but the GPS receiver and antenna were quite close to both the Pi and the web-cam in the payload. The next time I'll add screening and increase the distance a little.

However, the image data was coming in perfectly, not only through my antenna and receiver at home, but also via other

Photo 11: Raspberry Pi image from the landing spot.

receivers around the country. As the balloon got higher the pictures got better, and more receivers started getting good data, with some image data even being received as far away as Northern Ireland (over 500 km away—not bad for 10 mW!). Now a PIE flight isn't complete without a PIE chart, so figure 2 is an example, showing the number of image packets received by different listeners (thanks to all!)

Meanwhile, the first flight was creeping up the altitude table, eventually reaching the #4 position only 300-odd meters below the world record. Part of me was hoping it would go higher, but part was happy that it didn't knock me down from my #2 spot in the table! The balloon then burst, and initially the descent looked perfectly normal. However, most of the balloon was still attached, and it managed to produce a parachute-like shape which slowed the descent to only 2 meters per second at an altitude where it should have been doing at least five times that! Turning to the main flight, it was sending in image after image without errors, and each image being better than the last as the balloon went higher and higher.

We were expecting it to burst at around 34 km, but obviously the balloon wasn't aware of our calculations. It went through 34 km, and 35, and .... eventually burst just a few meters short of 40 km (39,994 meters to be exact, putting it at 12th place in the UK altitude record table).

Quite amazing for a medium-size balloon with about 1 kg of payloads underneath it! With both balloons having burst it was time to get going in the chase cars, both of which were equipped with aerials, radio receivers, netbooks or car PCs for decoding and mapping, and 3G internet.

The landing prediction for the main flight was near Didcot, so we headed there and parked up to check on the latest prediction. We weren't far away when the payloads landed at Milton Heights, just a few miles from the launch site. Amazingly, one of the receivers was close enough to still be picking up live images, and after a while everyone could see that the payload had landed safely in long grass (photo 11).

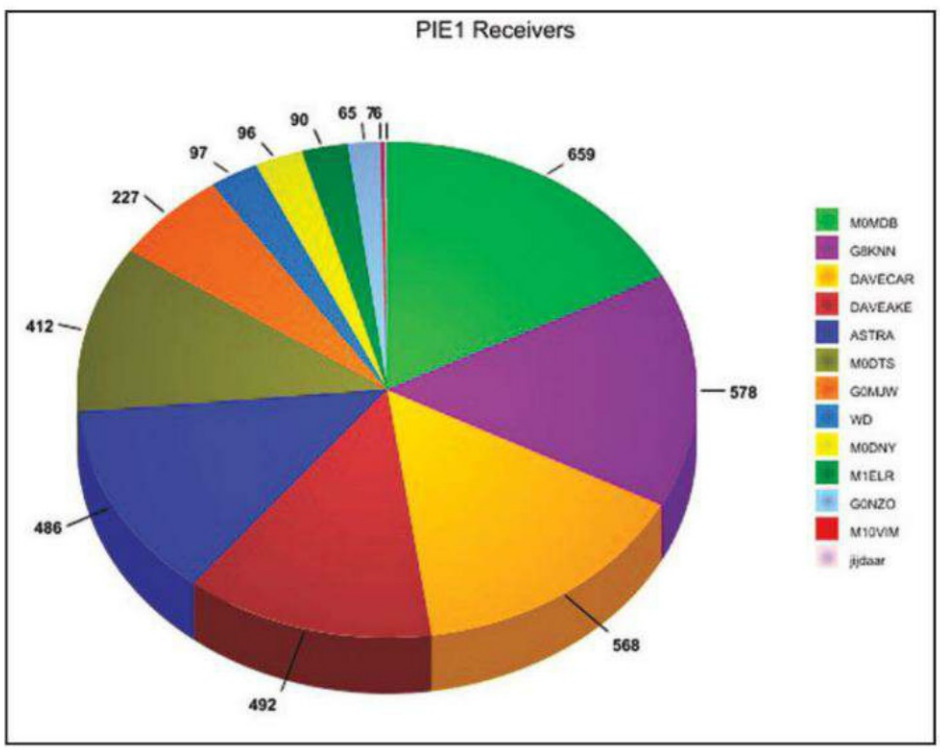

Figure 2. The pie chart showing the number of image packets received by different listeners.

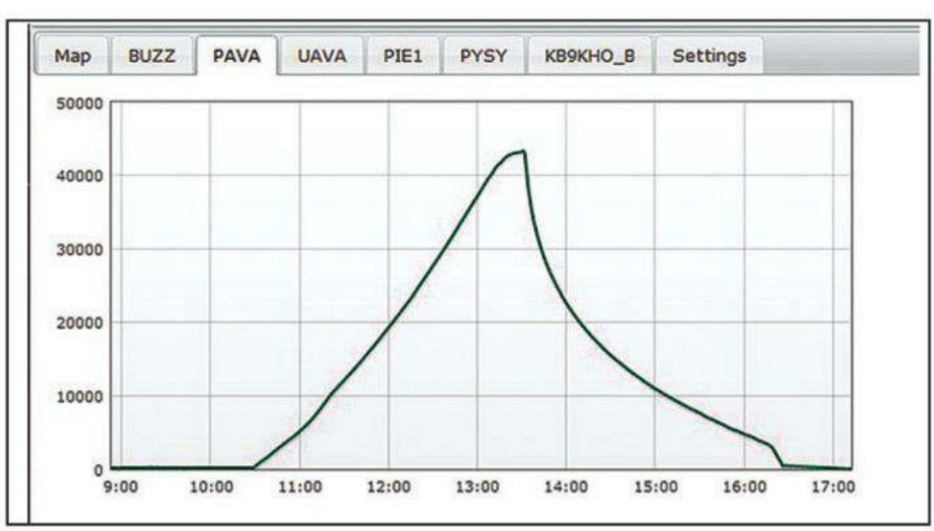

Figure 3. The very unusual altitude plot for the PAVA launch.

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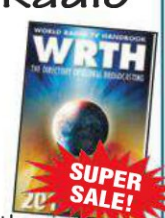

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Photo 12. Anthony Stirk, 2EØUPU, left, and the author, right, holding the recovered payloads from the UAVA launch.

Photo 13. The author holding the shard remains of the balloon of the PAVA launch.

Anthony saw the payloads first from his chase car, in long grass next to a football field. Having obtained permission from the club, we rescued all three payloads and the parachute (see photo 12). Meanwhile, the earlier flight was still coming down, but very, very slowly – less than one fifth of the expected rate! We didn't know at the time, but now we were pretty sure that the latex had managed to form its own parachute. Then, with a few km to go, it suddenly sped up (we think the latex tore) and landed in a field north of Oxford. Figure 3 shows the very unusual altitude plot for the PAVA launch.

It took a while for us to get the final position, but having done so it seemed that it was in a rather inaccessible location. With the rain pouring down, Anthony decided to call it a day rather than try to retrieve what was only £50-worth of tracker. He then drove off, and I went online to tell the other receivers in the UKHAS chat room that I was about to go home, too. "Ah, but it's near a layby on the A34" I was told, "easy to get to" and "the rain will pass in 5 minutes." Well, that didn't sound so bad, so I set off north up the A34, then back southbound to get to the layby.

Well, of those three statements, one was correct—it was just 155 m from the layby. However, the rain just kept on coming, only easing from torrential to very heavy as we sat in the car waiting. Eventually I decided to just go for it, and crawled past trees and bushes to find … a field full of 5-ft. high maize. No chance of seeing the payload from there, although I tried. After failing, I went back to the car to get my Android® phone loaded with HamGPS software that guides you to a target location. It took a lot of effort to get there, and for a while I felt like I was starring in "Dave of the Triffids," but as I got to the target position I walked into the nylon cord between the payload and remains of the balloon! It really wasn't visible at all until I was almost on top of it. Photo 13 shows me emerging, successful, after my expedition.

Thanks go to Anthony Stirk, 2EØUPU, for driving down from sunny Yorkshire to grimmest, darkest Berkshire for the launch and supplying the GoPro HD footage, to Philip Heron for providing the webcam imaging and image encoding software, to Nick for coming along to help out, and of course to my wife Julie for keeping us fed and watered during the day and for driving my chase car whilst I did the techie stuff.

All in all, a great day HABbing. All fourtrackers worked well, all were recovered, and we got some stunning live images back. For more information on this fascinating hobby, visit the UKHAS web site (http://www.ukhas.org.uk/). For more images and video, see the sidebar "More Information and Details."

More Information and Details

All SSDV images: <http://www.flickr.com/photos/daveake/sets/72157630589478676/>
Photos from the day: <http://www.flickr.com/photos/daveake/sets/72157630584759530/>
pAVA Inflation Time-Lapse: <http://youtu.be/gloJM3O2DNo>
Burst video from the GoPro: <http://youtu.be/KGLB9-LdpYM>
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Recovery of PIE1, uAVA, and BUZZ8: <http://youtube/Ui_wejYGV u0>
Anthony's write-up: <http://ava.upuaut.net/?p=315&cpage=1#comment -927>
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